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(54) **TERMINATION OF CARBON NANOTUBE MACROSTRUCTURES**

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Related U.S. Application Data

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(51) **Int. Cl.**

H01R 11/03 (2006.01)
H01R 13/03 (2006.01)
H01R 4/18 (2006.01)

(52) **U.S. Cl.**

CPC ***H01R 13/03*** (2013.01); ***H01R 4/188*** (2013.01)

(58) **Field of Classification Search**

CPC H01R 4/363; H01R 4/20
USPC 439/791, 787, 805, 845, 784, 884, 885, 439/880, 433, 444
See application file for complete search history.

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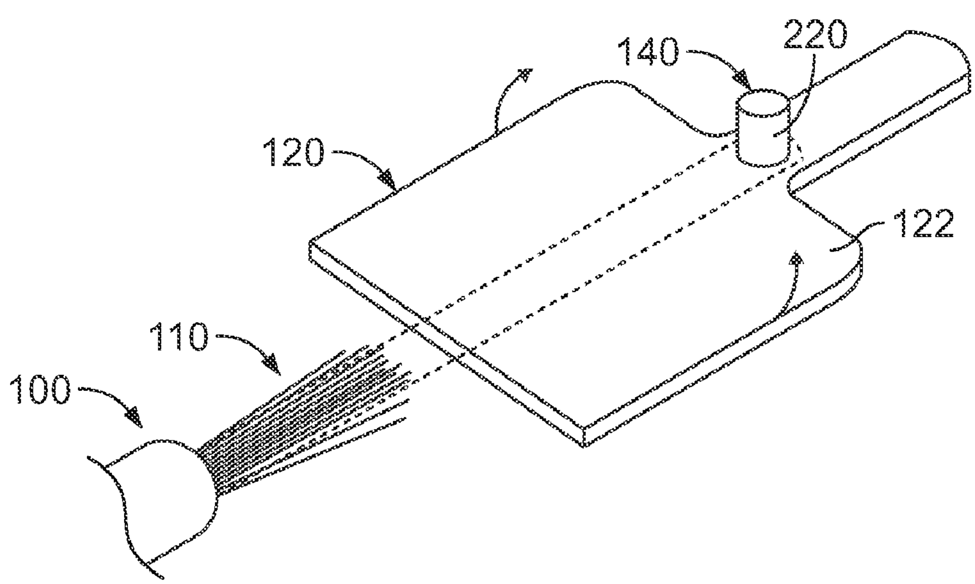
Primary Examiner — Phuongchi T Nguyen

(57) **ABSTRACT**

An electrical connector has a carbon nanotube (CNT) conductor, a terminal terminated to the CNT conductor, and a conductive intermediary electrically coupled to the CNT conductor and the terminal to enhance an electrical connection between the CNT conductor and the terminal. Optionally, the terminal may have a crimp barrel that receives the CNT conductor. The electrical connector may include a second CNT conductor where the terminal splices the CNT conductor and the second CNT conductor together.

10 Claims, 4 Drawing Sheets



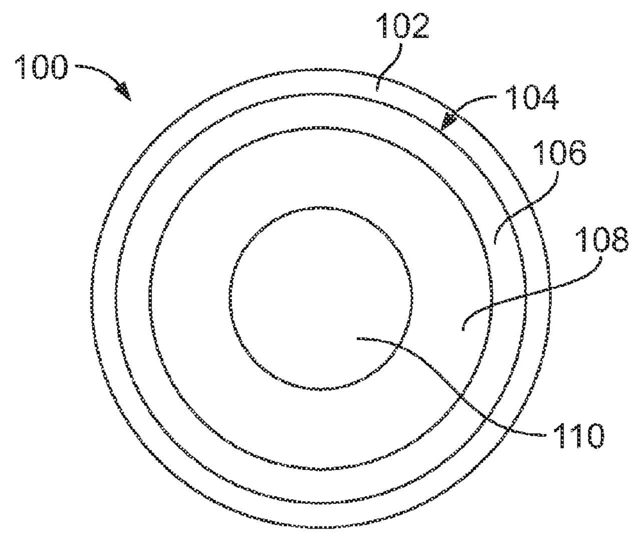


FIG. 1

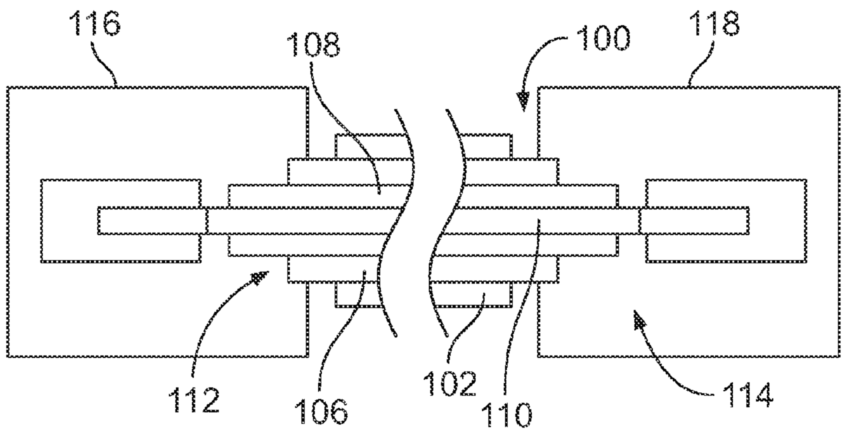


FIG. 2

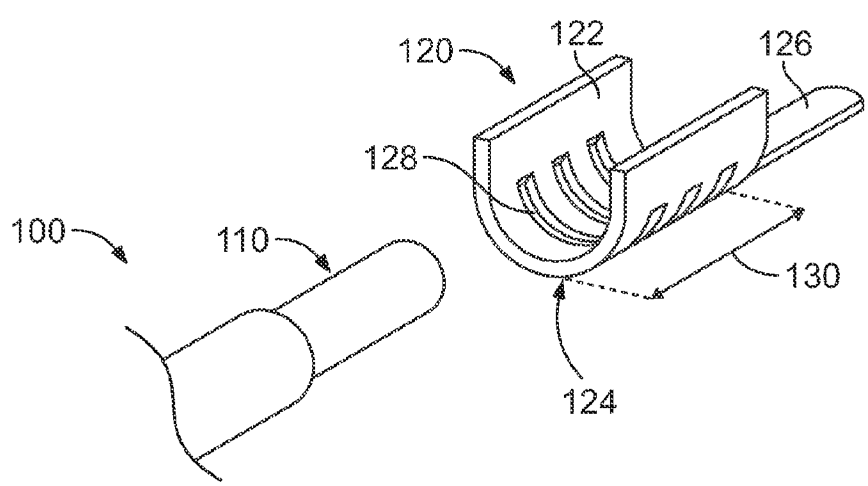


FIG. 3

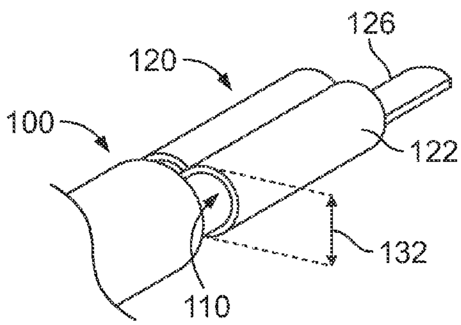


FIG. 4

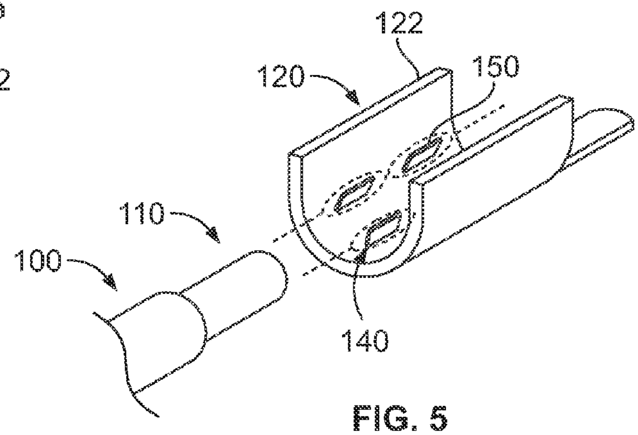


FIG. 5

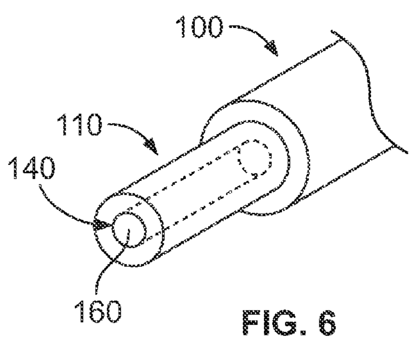


FIG. 6

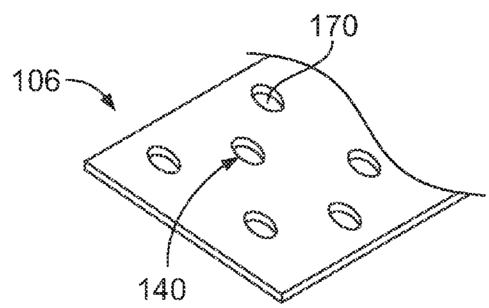


FIG. 7

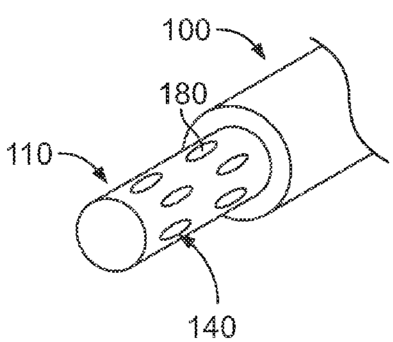


FIG. 8

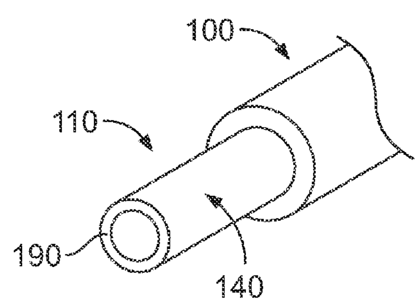


FIG. 9

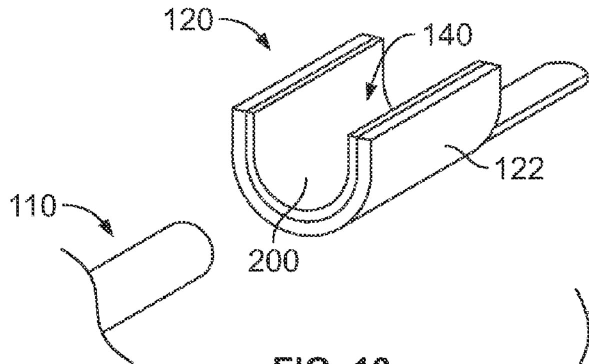


FIG. 10

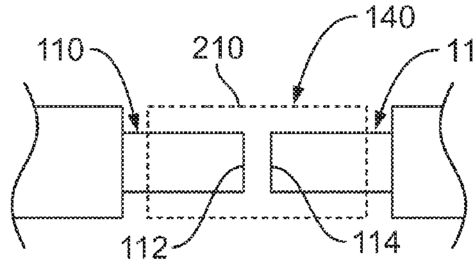


FIG. 11

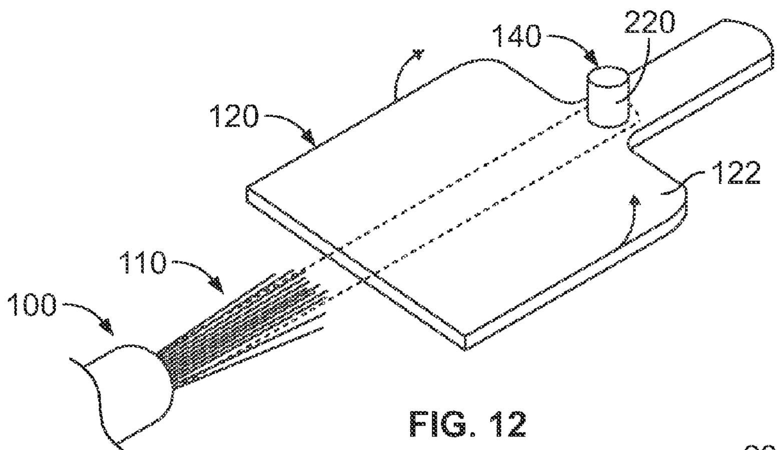


FIG. 12

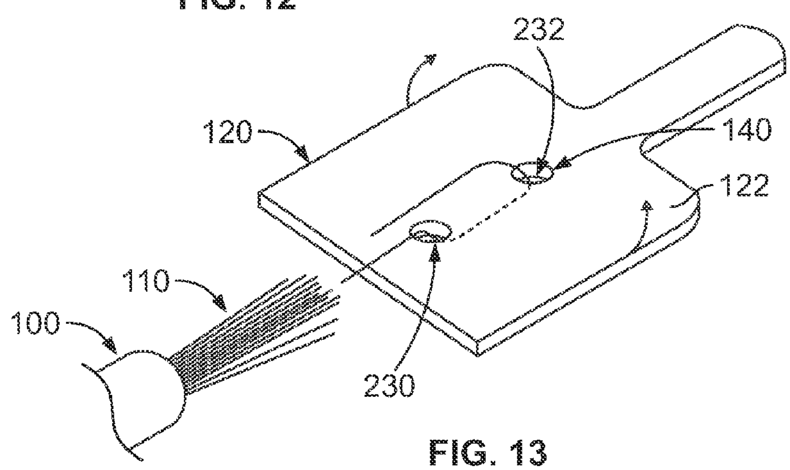


FIG. 13

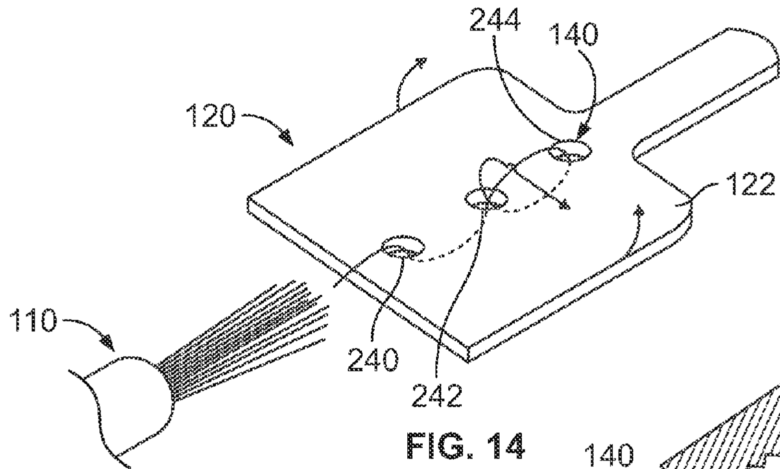


FIG. 14

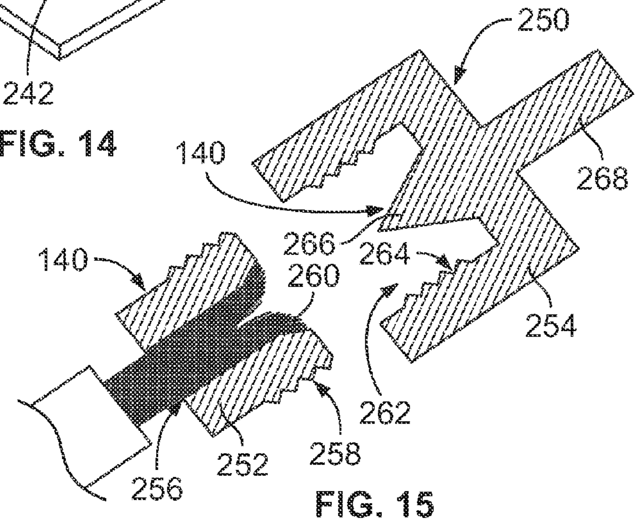


FIG. 15

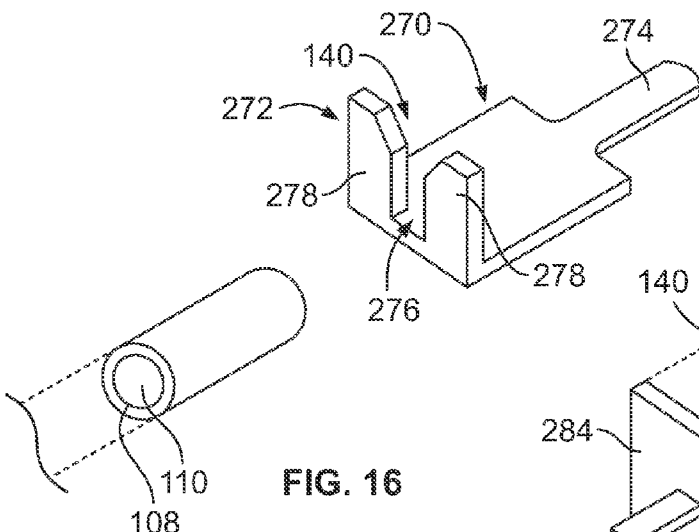


FIG. 16

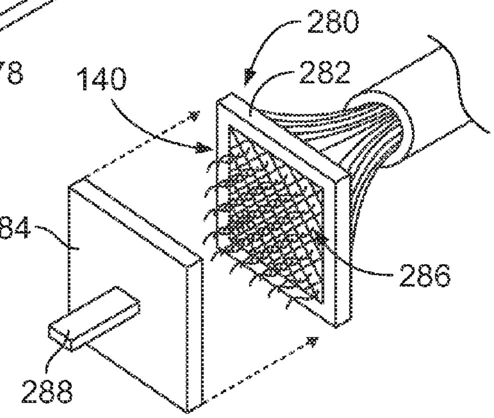


FIG. 17

TERMINATION OF CARBON NANOTUBE MACROSTRUCTURES

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/599,612 filed on Feb. 16, 2012, the subject matter of which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

The subject matter herein relates generally to termination of carbon nanotube (CNT) macrostructures.

CNTs are carbon-based networks that have use in a wide range of applications. Due to the electrical conductivity exhibited by CNTs, CNTs have application in electrical systems, such as use as electrical conductors of cables, wires or other conductors, as electromagnetic interference (EMI) shielding for cables or other types of electronic components, and other applications. Due to the relative light weight of CNTs, as compared to traditional metal components, CNTs have application in aeronautical application where weight is a significant design factor.

CNTs for use as electrical conductors are not without disadvantages. For instance, termination of CNTs to terminals or other conductive elements or splicing of CNTs to other CNTs has proven difficult. A need remains for termination methods and components for termination CNTs.

BRIEF DESCRIPTION OF THE INVENTION

In one embodiment, an electrical connector is provided having a carbon nanotube (CNT) conductor, a terminal terminated to the CNT conductor, and a conductive intermediary electrically coupled to the CNT conductor and the terminal to enhance an electrical connection between the CNT conductor and the terminal. Optionally, the terminal may have a crimp barrel that receives the CNT conductor. The electrical connector may include a second CNT conductor where the terminal splices the CNT conductor and the second CNT conductor together.

Optionally, the conductive intermediary may be integrally formed with the crimp barrel. The conductive intermediary may include fins extending from the crimp barrel with CNT strands of the CNT conductor being laced between the fins. The conductive intermediary may include a conductive layer on at least one of the crimp barrel and the CNT conductor. The conductive layer may be malleable and formed into the CNT conductor when heat and/or pressure is applied to the conductive layer. The conductive intermediary may include a soft metal that conforms to and spreads into the CNT conductor. The conductive intermediary may include a conductive paste on at least one of the crimp barrel and the CNT conductor.

Optionally, the conductive intermediary may include conductive fillers in the CNT conductor between CNT strands of the CNT conductor that engage the terminal. The conductive intermediary may include a metallic wire received in the CNT conductor.

Optionally, the conductive intermediary may include a post extending from the terminal. The CNT conductor may be wrapped around the post and doubled back into the crimp barrel. The conductive intermediary may include openings in the crimp barrel through a body defining the terminal. The CNT conductor may be laced into and out of the crimp barrel through the openings.

Optionally, the terminal may be a multi-piece body with the CNT conductor being sandwiched between the pieces of the terminal. The terminal may include an inner body and an outer body. The outer body may have a wedge that is driven into an end of the CNT conductor to engage the CNT conductor. The inner body may have a screen with screen openings. CNT strands of the CNT conductor may be laced through the screen and sandwiched between the inner and outer bodies.

Optionally, the conductive intermediary may include blades with a gap therebetween extending from the terminal. The blades and the gap may define an insulation displacement contact with the CNT conductor being loaded into the gap and the blades engaging the CNT conductor. Interior surfaces of the blades may be made of soft metal that deforms and spreads into the CNT conductor between CNT strands of the CNT conductor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view of a cable formed in accordance with an exemplary embodiment.

FIG. **2** illustrates a cable extending between a first end and a second end.

FIG. **3** illustrates the cable poised for termination with a terminal **120**.

FIG. **4** illustrates the terminal terminated to the cable.

FIG. **5** shows the terminal formed in accordance with an exemplary embodiment.

FIG. **6** shows the CNT conductor formed in accordance with an exemplary embodiment.

FIG. **7** shows the CNT conductor formed in accordance with an exemplary embodiment.

FIG. **8** shows the CNT conductor formed in accordance with an exemplary embodiment.

FIG. **9** shows the CNT conductor formed in accordance with an exemplary embodiment.

FIG. **10** shows the terminal formed in accordance with an exemplary embodiment.

FIG. **11** illustrates ends of two cables being spliced together.

FIG. **12** shows the terminal formed in accordance with an exemplary embodiment.

FIG. **13** shows the terminal formed in accordance with an exemplary embodiment.

FIG. **14** shows the terminal formed in accordance with an exemplary embodiment.

FIG. **15** illustrates a terminal formed in accordance with an exemplary embodiment.

FIG. **16** illustrates a terminal formed in accordance with an exemplary embodiment.

FIG. **17** illustrates a terminal formed in accordance with an exemplary embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments described herein provide termination methods and components for CNT conductors. Embodiments have features that aid in providing an electrical and mechanical connection between a terminal and a CNT conductor.

FIG. **1** is a cross-sectional view of a cable **100** formed in accordance with an exemplary embodiment. The cable **100** includes a jacket **102** defining a core **104**. An EMI shield **106** is in the core **104** and is surrounded by the jacket **102**. An insulator **108** is in the core **104** and is surrounded by the EMI shield **106**. A center conductor **110** is in the core **104** and is surrounded by the insulator **108**. The insulator **108** electrically isolates the center conductor **110** from the EMI shield **106**. The insulator **108** is manufactured from a dielectric material. Optionally, the insulator **108** may be a shrink tube that is heat shrinkable. The jacket **102** is manufactured from a dielectric material. Optionally, the jacket **102** may be a shrink tube that is heat shrinkable. Optionally, the cable **100** may include a drain or ground wire.

The EMI shield **106** and the center conductor **110** are electrically conductive. The cable **100** defines a coaxial cable having the center conductor **110** and an outer conductor defined by the EMI shield **106** extending along a common axis along the length of the cable **100**. The cable **100** may be another type of cable, such as a twin-axial cable, a quad-axial cable, an unshielded cable, and the like. The center conductor **110** is configured to convey electrical signals between a first end **112** (shown in FIG. **2**) and a second end **114** (shown in FIG. **2**) of the cable **100**. In an exemplary embodiment, the center conductor **110** is configured to convey data signals. Alternatively, the center conductor **110** may convey power between the first and second ends **112**, **114**. In other alternative embodiments, the cable **100** may include more than one center conductors that define different electrical paths to convey different electrical signals.

In an exemplary embodiment, the center conductor **110** and the EMI shield **106** are manufactured from a carbon-based substrate, such as carbon nanotubes (CNTs). The CNTs faun a network that defines a CNT macrostructure, such as a wire, a tape, a foil, a braid, or other usable structure that may be handled and processed to manufacture the cable **100** or other electronic components. The CNT macrostructure is made of many CNT nanostructures. Other types of carbon-based substrates may include graphene, a graphite oxide structure, and the like. Alternatively, the center conductor **110** and the EMI shield **106** are manufactured into a macrostructure from another nano-substrate, such as a ceramic nanowire, such as a boron nitride substrate. The description hereinafter refers to the carbon-based substrate as a CNT network. The CNT network may be used in other types of electronic components other than a cable, such as a passive dielectric or insulating component. The CNT network may be modified to make a compounded or composite network having particles other than carbon nanotubes to enhance characteristics of the CNT macrostructure.

The center conductor **110** defines a CNT conductor, and may be referred to hereinafter as a CNT conductor **110**. Optionally, the center conductor **110** may include one or more strands of CNT conductors that are twisted together during a cable forming process. Each strand may be a separate CNT conductor manufactured from a CNT network.

The EMI shield **106** defines a CNT conductor, and may be referred to hereinafter as a CNT conductor **106**. In an alternative embodiment, only the center conductor **110** is manufactured from a CNT network. In another alternative embodiment, only the EMI shield **106** is manufactured from a CNT network.

The CNT network includes a plurality of CNT fibers that are arranged to form a framework that defines the CNT network. The framework may be pulled or drawn from a CNT array or CNT source, such as by using a spinning technique. The framework may be formed into a yarn or wire. The framework may be a braided yarn or a mesh. Alternatively, the framework may be formed into a tape. Alternatively, the framework may be formed into a sheet. The wire, tape or sheet may have any length depending on the particular application. A wire is defined as having a width that is less than approximately two times a thickness of the framework. A tape is defined as having a width that is greater than approximately two times the thickness of the framework and having a width that is less than approximately ten times the thickness of the framework. A sheet is defined as a framework having a width that is greater than approximately ten times the thickness of the framework. The framework may have different shapes depending on the particular application.

The wires or yarns may be used, for example, to define the strands of the center conductor **110**. The tapes may be used, for example, to form the EMI shield **106**, wherein the tape may be wrapped around the internal components of the cable **100** such that the opposite edges of the tape touch one another or overlap one another. In other embodiments, the tape may be wrapped in a helical manner around the insulator **108** and center conductor **110** to form an EMI shield. In other alternative embodiments, the tapes may be used to form wires or conductors of a cable, such as by drawing the tape during a cable forming process. The sheet may be used, for example, as an EMI shield that covers an electrical component, such as a housing of a connector to provide EMI shielding for the connector. The framework may have any other shape suitable for the particular application capable of being formed from a CNT structure.

In an exemplary embodiment, each CNT conductor **106**, **110** is manufactured from a CNT network that is combined with fillers, such as metallic fillers, organometallic fillers, or other types of fillers, to form a composite conductor. The fillers may be used to enhance the ability to terminate the CNT conductor **106**, **110**. The fillers may be used to enhance an electrical characteristic or other characteristic of the CNT conductor **106**, **110**. The fillers may be particles, flakes, large bodies or structures suspended in or passing through the CNT conductors **106**, **110**, plating, encapsulated pellets, or other additives in or on the CNT conductors **106**, **110**.

In an exemplary embodiment, the fillers are applied by bathing the CNT network in a solvent bath that includes a solvent and the additive particles in the solution. The composite conductor is then processed to remove the solvent and/or react the additive particles with the CNT network. For example, the composite conductor may be subjected to heating, cooling, annealing, densifying, thickening, winding, plying, braiding, functionalizing and the like. The additive particles may be applied by other processes in alternative embodiments, such as physical vapor deposition, chemical vapor deposition, dip coating, or other processes to apply the additive particles to the CNT network. The fillers may extend or permeate entirely through the CNT network such that the fillers are between the fibers of the CNT network. The fillers may be a coating on or between individual fibers or yarns in a network or braid. The fillers may penetrate the fibers or yarns that make up the network or braid. In other embodiments, the CNT network may be inserted into an aqueous bath having additive particles in suspension rather than a solvent bath.

FIG. **2** illustrates the cable **100** extending between the first and second ends **112**, **114**. The cable **100** may have any length defined between the first and second ends **112**, **114**. The first end **112** is terminated to a first electrical component **116**. The second end **114** is terminated to a second electrical component **118**.

The first and second electrical components **116**, **118** are represented schematically in FIG. **2**. The first and second electrical components **116**, **118** may be any type of electrical component. Optionally, the first electrical component **116** may be different than the second electrical component **118**. The electrical components **116**, **118** may be electrical contacts, electrical connectors, circuit boards, or other types of electrical components. In an exemplary embodiment, the first and/or second electrical components **116**, **118** are crimped to the cable **100**. The cable **100** may be terminated by other means or processes in alternative embodiments, such as soldering, welding, adhering, bonding and the like.

The center conductor **110** and/or EMI shield **106** are mechanically and electrically connected to the electrical components **116**, **118**. The center conductor **110** and/or EMI shield **106** create an electrical path between the first and second electrical components **116**, **118**.

In an exemplary embodiment, the CNT network of the CNT conductor is conductive and is configured to convey electrical signals between the first and second electrical components **116**, **118**. The fillers may enhance the electrical properties of the center conductor **110** and/or EMI shield **106**. For example, the conductivity of the center conductor **110** and/or EMI shield **106** may be increased by selecting a filler material having a high conductivity. The fillers may be selectively located along the cable **100**, such as proximate to the first and second ends **112**, **114** to enhance the termination of the CNT network to the electrical components **116**, **118**. For example, the fillers may enhance the ability of the CNT network to be crimped to a terminal.

The cable **100** and electrical components **116**, **118** define an electrical connector. The CNT network may be used in other types of electrical systems other than a cable. For example, the CNT network may be used in another type of electrical connector, a microprocessor, or any type of electrical component suitable for use with CNTs.

FIG. **3** illustrates the cable **100** poised for termination with a terminal **120**. FIG. **4** illustrates the terminal **120** terminated to the cable **100**. The cable **100** is illustrated without the EMI shield **106** or jacket **102** (both shown in FIG. **1**). The CNT conductor **110** is illustrated in FIGS. **3** and **4**.

In an exemplary embodiment, the terminal **120** is configured to be crimped to the CNT conductor **110**. The terminal **120** includes a crimp barrel **122** at a termination end **124** thereof. A contact **126** is provided at a mating end of the terminal **120**. The contact **126** extends from the crimp barrel **122**. In the illustrated embodiment, the contact **126** is a pin contact. The terminal **120** may have other mating interfaces in alternative embodiments, such as a socket, spring beam, faston tab, or other conventional mating interfaces. The terminal **120** may not have any contact in other embodiments, such as a terminal used to splice the ends of two cables **100** together, or a terminal that is used to electrically terminate the EMI shield to a connector, such as around a cylindrical protrusion of a connector.

The crimp barrel **122** may be formed in a U-shape to receive the CNT conductor **110**. The edges of the crimp barrel **122** are folded in during the crimping process around the CNT conductor **110** to terminate the terminal **120** to the CNT conductor **110**. In the illustrated embodiment, the terminal **120** includes striations **128** defined by grooves or rails that provide surfaces for gripping the CNT conductor **110**. Alternatively, the terminal **120** may not include any striations **128**. The crimp barrel **122** has a length **130**. As shown in FIG. **4**, the terminal **120** has a crimp height **132** when crimped to the CNT conductor **110**.

To achieve a good mechanical and electrical termination to the CNT conductor **110**, the terminal **120** may have different characteristics than a conventional terminal **120** terminated to copper wires. Certain characteristics of the terminal **120** may be varied to achieve a good termination. For example, characteristics such as the base metal of the terminal **120**, the length of the crimp barrel **122**, the crimp height **132**, the size, shape and number of striations, and the like may be variable and selected to achieve a good termination. Changes in one characteristic may affect the other characteristics.

In an exemplary embodiment, because the CNT conductor **110** has a tendency for high compression during the crimp (as compared to copper wire strands), it may be desirable to select a base metal that is stiffer than typical base metals for terminals that crimp to copper wires. For example, the base metal of the terminal **120** may be brass, phosphor-bronze or another base metal that is harder and has less relaxation than copper or copper-alloy terminals. Termination to the CNT conductor **110** should be taken into account when selecting the material from the base metal of the terminal **120**.

The length **130** of the crimp barrel **122** has an effect on the mechanical and electrical termination between the CNT conductor **110** and the terminal **120**. Having a longer crimp barrel **122** allows for more contact between the CNT conductor **110** and the crimp barrel **122**, increasing the mechanical and electrical termination.

The crimp height **132** has an effect on the mechanical and electrical termination between the CNT conductor **110** and the terminal **120**. Having a short crimp height may compress the crimp barrel **122** too much, leading to damage of the CNT conductor **110**, particularly when the terminal **120** is manufactured from a harder base metal. Having a taller crimp height **132** may lower the mechanical connection therebetween, which may require a longer crimp barrel **122** to accommodate for the weaker mechanically connection.

In an exemplary embodiment, consideration is given to the striations **128** when designing the terminal **120** for termination to the CNT conductor **110**, as compared to copper wires. The striations **128** may cause damage to, such as severing of, the CNT strands. The striations **128** may be completely removed to eliminate damage therefrom. Alternatively, the size and shape of the striations **128** may be designed to reduce damage therefrom. For example, the edges of the striations **128** may transition gradually as opposed to having sharp edges.

To enhance the electrical and/or mechanical termination, the CNT conductor **110** and/or the terminal **120** may include conductive intermediaries **140** at the interface between the CNT conductor **110** and the terminal **120**. Examples of conductive intermediaries **140** are described below. Other types of conductive intermediaries **140** may be provided in other embodiments.

FIG. **5** shows the terminal **120** formed in accordance with an exemplary embodiment. The terminal **120** has conductive intermediaries **140** in the form of protrusions or fins **150** extending into the receiving space of the crimp barrel **122**. The fins **150** are integral with the terminal **120**. The fins **150** may be stamped and formed from the terminal **120**. The fins **150** may be attached to the terminal **120**. The fins **150** may be generally planar structures extending radially outward or outward at other angles from the terminal **120**. The fins **150** may be have other shapes, such as mound shapes like bumps extending into the receiving space. The fins **150** may be rigid. The fins **150** may bend or move during crimping.

The fins **150** spread and separate the CNT strands. The strands of the CNT conductor **110** are laced around and between the fins **150** (exemplary paths of the strands around the fins **150** are illustrated in FIG. **5**). For example, the exposed end of the CNT conductor **110** may be separable to allow the strands to fit between and around the fins **150**. The exposed end of the CNT conductor **110** may naturally fray or splay when cut. The frayed CNT strands may naturally seat in the crimp barrel **122** around the fins **150**. The fins **150** engage the CNT strands to increase the surface area of the interface between the terminal **120** and the CNT conductor **110**.

FIG. **6** shows the CNT conductor **110** formed in accordance with an exemplary embodiment. The CNT conductor

110 has a conductive intermediary 140 in the form of a metal wire 160 loaded into the end of the CNT conductor 110. The wire 160 may be threaded into the CNT conductor 110 or may be pulled into the CNT conductor during the cable forming process. Optionally, the metal wire 160 may extend the entire length of the cable 100 (shown in FIG. 1). The wire 160 is internal of the CNT conductor 110. The wire 160 is surrounded by the CNT strands. The metal wire 160 provides central support for the CNT conductor 110 to support the CNT strands during crimping. The CNT strands electrically engage the wire 160. Optionally, the terminal 120 (shown in FIG. 3) may engage the wire 160 when crimped to the CNT conductor 110. The wire 160 may extend from the CNT conductor 110 and be electrically terminated to the terminal 120 or another component.

FIG. 7 shows the CNT conductor 106 (defining the EMI shield 106) formed in accordance with an exemplary embodiment. The CNT conductor 106 has conductive intermediaries 140 in the form of metal fillers 170 loaded into the CNT network. The metal fillers 170 may be metal flakes or other metal fillers. The metal fillers 170 may extend entirely through the CNT network or may extend only partially through the CNT network. The metal fillers 170 are surrounded by the CNT strands. The CNT strands electrically engage the metal fillers 170. When crimped, a terminal may engage the metal fillers 170.

FIG. 8 shows the CNT conductor 110 formed in accordance with an exemplary embodiment. The CNT conductor 110 has conductive intermediaries 140 in the form of metal fillers 180 loaded into the CNT network, The metal fillers 180 may be metal flakes or other metal fillers. The metal fillers 180 may extend entirely through the CNT network or may extend only partially through the CNT network. The metal fillers 180 are surrounded by the CNT strands. The CNT strands electrically engage the metal fillers 180. When crimped, the terminal 120 (shown in FIG. 3) may engage the metal fillers 180.

Optionally, the metal fillers may be encapsulated pellets. The pellets may hold a conductive substance or particles therein. The pellets may be fractured under mechanical stress, such as when crimped, releasing the conductive substance and creating a bond with the CNT strands and/or the terminal 120. The pellets may be fractured or opened by other means or processes such as application of microwave energy, heat, exposure to another substance and the like. The conductive substance may be in a liquid form. The conductive substance may be malleable and may form to or spread between the CNT strands when heat and/or pressure are applied during the crimping process.

FIG. 9 shows the CNT conductor 110 formed in accordance with an exemplary embodiment. The CNT conductor 110 has a conductive intermediary 140 in the form of a conductive layer 190 surrounding and/or embedded in the CNT network. The conductive layer 190 may be a plating layer surrounding the CNT conductor 110. The conductive layer 190 may be plating layers surrounding each individual strand. The conductive layer 190 may be a coating applied to the CNT conductor 110. The conductive layer 190 may be a conductive paste. The conductive layer 190 may extend entirely through the CNT network or may extend only partially through the CNT network. The conductive layer 190 engages the CNT strands. The conductive substance may be malleable and may form to or spread between the CNT strands when heat and/or pressure are applied during the crimping process. For example, the conductive layer 190 may be a soft metal such as tin or other solders made of metal alloys that conform and spread into the CNT network when placed under heat and/or pressure. For example, the conductive layer 190 may be made of indium, gallium, a monomeric organic based composite material with metallic fillers, a polymeric organic based composite material with metallic fillers, and the like. When crimped, the terminal 120 (shown in FIG. 3) may engage the conductive layer 190. Optionally, the terminal 120 may include a plating layer to enhance electrical connection between the terminal 120 and the CNT conductor 110.

FIG. 10 shows the terminal 120 formed in accordance with an exemplary embodiment. The terminal 120 has a conductive intermediary 140 in the form of a conductive layer 200 formed on the interior surface of the crimp barrel 122. The conductive layer 200 may be a plating layer. The plating layer may be a precious metal plating, such as gold plating. The plating layer may be a tin plating layer. Optionally, if the conductive layer 200 is formed of a substance that tends to oxidize or form an oxide layer, the conductive layer 200 may be subjected to a process, such as an etching or treating process, to remove the oxide layer for better electrical connection between the base metal of the terminal 120 and the CNT conductor 110. For example, a chemical etching, or chemical treatment of the conductive layer 200 may make the conductive layer 200 more conductive. The conductive layer 200 may be a coating applied to the surface. The conductive layer 200 may be a conductive paste. When the CNT conductor 110 is loaded into the terminal barrel 122, the conductive layer 200 engages the CNT strands. The conductive substance may be malleable and may form to or spread between the CNT strands when heat and/or pressure are applied during the crimping process.

FIG. 11 illustrates ends 112, 114 of two cables 100 being spliced together. A conductive intermediary 140 in the form of a conductive body 210 is applied to the ends 112, 114 of the cables 100. The conductive body 210 may be a layered build-up of coatings applied to the ends 112, 114. The conductive body 210 may be applied as a liquid, such as in a bath. The conductive body 210 may be applied as a paste that is later hardened. The conductive body 210 may be malleable and may form to or spread between the CNT strands when heat and/or pressure are applied. The conductive body 210 may be cured under application of heat, microwave energy, light or chemical reaction with another compound such as a hardener.

FIG. 12 shows the terminal 120 formed in accordance with an exemplary embodiment. The terminal 120 has a conductive intermediary 140 in the form of a post 220 extending from the terminal 120 forward of the crimp barrel 122. The post 220 is integral with the terminal 120. The post 220 may be stamped and formed from the terminal 120. The post 220 may be separately attached to the terminal 120.

The CNT conductor 110 is wrapped around the post 220 and doubles back through the crimp barrel 122. The post 220 fits between the folded over strands. Wrapping the CNT conductor 110 around the post provides a mechanical advantage against removal of the CNT conductor 110 from the crimp barrel 122 after crimping. The frayed ends of the CNT strands may be captured within the crimp barrel 122. During crimping, the sides of the crimp barrel 122 are crimped around the CNT conductor 110.

FIG. 13 shows the terminal 120 formed in accordance with an exemplary embodiment. The terminal 120 has a conductive intermediary 140 in the form of openings 230, 232 through the body of the terminal 120 within the crimp barrel 122. The openings 230, 232 receive the CNT conductor 110. The CNT conductor 110 is laced through the opening 230 and then through the opening 232 back into the crimp barrel. The body of the terminal 120 fits between strands of the CNT conductor **110**. The CNT conductor **110** doubles back through the crimp barrel **122**. Wrapping the CNT conductor **110** through the openings **230**, **232** provides a mechanical advantage against removal of the CNT conductor **110** from the crimp barrel **122** after crimping. The frayed ends of the CNT strands may be captured within the crimp barrel **122**. During crimping, the sides of the crimp barrel **122** are crimped around the CNT conductor **110**.

FIG. **14** shows the terminal **120** formed in accordance with an exemplary embodiment. The terminal **120** has a conductive intermediary **140** in the form of openings **240**, **242**, **244** through the body of the terminal **120** within the crimp barrel **122**. The openings **240**, **242**, **244** receive the CNT conductor **110**. The CNT conductor **110** is laced through the opening **240**, through the opening **242** back into the crimp barrel **122**, out of the opening **244**, back through the opening **242** into the crimp barrel **122** and tied under itself. The body of the terminal **120** fits between strands of the CNT conductor **110**. Wrapping the CNT conductor **110** through the openings **240**, **242**, **244** provides a mechanical advantage against removal of the CNT conductor **110** from the crimp barrel **122** after crimping. The frayed ends of the CNT strands may be captured within the crimp barrel **122**. During crimping, the sides of the crimp barrel **122** are crimped around the CNT conductor **110**.

FIG. **15** illustrates a multi-piece terminal **250** having an inner body **252** and an outer body **254**. The inner body **252** receives the CNT conductor **110** through an opening **256**. The inner body **252** and/or outer body define a conductive intermediary **140**. The inner body **252** has external threads **258**. The inner body **252** has angled surfaces **260** at the front of the inner body **252**. The CNT strands of the CNT conductor **110** engage the angled surfaces **260** to electrically connect the CNT conductor and the inner body **252**.

The outer body **254** has a chamber **262** that receives the inner body **252**. The walls of the chamber **262** have internal threads **264** that threadably engage the external threads **258** of the inner body to secure the inner body **252** to the outer body **254**. Other types of securing features may be used in alternative embodiments. A wedge **266** extends into the chamber **262**. The wedge **266** defines a conductive intermediary **140**. The wedge **266** is driven into the CNT conductor **110**. The wedge **266** splits the CNT strands and presses the CNT strands against the angled surfaces **260**. A mechanical and electrical connection is made between the CNT strands and both the inner and outer bodies **252**, **254**. A contact **268** extends from the outer body **254**.

FIG. **16** illustrates a terminal **270** having an insulation displacement contact (IDC) **272** at one end and a mating contact **274** at the opposite end. The IDC **272** receives the CNT conductor **110** through an opening **276**. The IDC **272** has two blades **278** that pierce the insulator **108** to engage the CNT conductor **110**. The blades **278** define conductive intermediaries **140**. The blades **278** press against the CNT conductor **110** to ensure electrical contact therewith. The finish on the blades **278** may be dull so as to not slice or damage the CNT strands. The finish on the blades **278** may be made of a soft material that can be deformed, reflowed and/or liquidized under pressure, heat, microwave energy, due to self induced heat generated from friction and the like. Such deformation/reflow/liquidization may conform and/or spread into the CNT network to enhance the electrical and/or mechanical connection.

FIG. **17** illustrates a multi-piece terminal **280** having an inner body **282** and an outer body **284**. The inner body **282** has a screen **286** that receives the frayed strands of the CNT conductor **110** through screen openings. The screen **286** defines a conductive intermediary **140**. The outer body **284** is pressed against the inner body **282**. The CNT strands are captured between the inner and outer bodies **282**, **284**. A mechanical and electrical connection is made between the CNT strands and both the inner and outer bodies **252**, **254**. A contact **288** extends from the outer body **284**.

Embodiments described herein provide robust termination methods and components for CNT conductors. Embodiments have features that aid in providing an electrical and mechanical connection between a terminal and a CNT conductor.

Mechanical adjustments to the design of a crimp can enable the CNT mechanical and electrical performance. Mechanical improvements include modifying design of striations, modifying the length of the crimp barrel and adjusting the height recommendation. Performance of the crimp can also be improved by changing the base metal of the crimp, which will modify the effective impact stress on the CNT structure.

Mechanical and electrical contact of CNT structures to metal terminals requires intimate contact between the metal and the CNT structure. Depending on the form of the CNT macrostructure, embodiments provide a feature within the crimp terminal either by plating or through stamping. The structure can be rigid and designed to separate and/or spread the CNT structure. The feature could be a stamped feature of the basic terminal that may be further formed during the crimping process. The feature could be a soft malleable coating that would conform and spread into the CNT structure mechanically when placed under heat and/or pressure. The addition of metal could be to the CNT macrostructure prior to the termination. The addition of metal could be accomplished physically, such as threading a metallic wire through the structure. The addition of metal could be accomplished via an intimate bond such as plating.

Mechanical and electrical contact of CNT structures to metal terminals requires intimate contact between the metal and the CNT structure. Depending on the form of the CNT macrostructure, embodiments apply a feature within the crimp terminal by processes such as, but not limited to plating or stamping. The structure could be soft malleable coating, such as a soft metal such as tin or other solders made of metal alloys that would conform and spread into the CNT structure mechanically when placed under heat and/or pressure. The addition of metal could be added to the CNT macrostructure prior to the termination. The addition of metal could be accomplished physically, such as threading a metallic wire through the structure or accomplished via an intimate bond such as plating.

Mechanical and electrical contact of CNT structures to metal terminals requires intimate contact between the metal and the CNT structure. Depending on the form of the CNT macrostructure, embodiments apply a feature within the crimp terminal by processes such as dispersion of liquid or application of paste. The structure could be soft malleable coating, such as suspension of particles of tin, or other solders made of metal alloys and/or soft metals such as In, Ga, or a organic (monomeric, polymeric) based composite material that is rendered electrically or thermally conductive by inclusion of metallic particles that would conform and spread into the CNT structure mechanically when placed under external pressure and cure solid under application of heat, microwave energy, light, or chemical reaction with another compound such as hardener. The addition of metal could also be a liquid metal or metallic particle dispersed in a solution that is encapsulated within a polymer. Under stress such as mechanical, heat, microwave, and the like, the encapsulant would fracture releasing the solution and creating the bond. The addition of metal could be added to the CNT macrostructure prior to the termination. The addition of metal could be accomplished physically, such as threading, co-braiding, metallic fibers or wires through the structure or accomplished via an intimate bond such as plating.

The lack of abrasion resistant and tendency to fray of CNT macrostructures create unique issues which can cause issues in termination designed to withstand both electrical and mechanical performance. Embodiments overcome this issue is by using a looping and/or pin interface within the termination. Embodiments include a stationary terminal element wrapped around with CNT macrostructure prior to crimping. Embodiments include a terminal post with a figure eight. Embodiments include a terminal loop with CNT macrostructure wrapped around and mechanically attached using techniques such as crimping or knotting afterwards. Embodiments include a plate, metallic or other material that is rigid in nature, which is than threaded with a CNT conductor. The structure could be self tightening or contain a feature such as a crimp.

Embodiments of termination of CNT macrostructures include a multi-piece terminal design which will create a pressure fit. The termination can be achieved by a swaging operation involving different pieces within the design. A blade having a soft finish is used to create the pressure. The blade may operate in different shapes including but not limited to knife edge, a screen, a ring, or cone shape. The pressure may be applied by a secondary, or multiple additional elements, which are used to help seat the CNT macrostructure and blade. The seating elements may include an interlocking feature such as a tread, external screws or clamps. The finish on the blade or the seating element could include a material that will not fray or cut the CNT macrostructure but may be required to displace the insulation on the macrostructure. The finish on the blade or on the seating element could be made of softer material than a bulk of that component. The finish layer could be deformed, re-flowed, or liquidized under application of pressure, heat, light, or microwave energy, or due to self-induced heat generated by friction. The finish material could conform and/or spread into the CNT structure.

It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from its scope. Dimensions, types of materials, orientations of the various components, and the number and positions of the various components described herein are intended to define parameters of certain embodiments, and are by no means limiting and are merely exemplary embodiments. Many other embodiments and modifications within the spirit and scope of the claims will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means—plus-function format and are not intended to be interpreted based on 35 U.S.C. §112, sixth paragraph, unless and until such claim limitations expressly use the phrase "means for" followed by a statement of function void of further structure.

What is claimed is:

1. An electrical connector comprising:

a carbon nanotube (CNT) conductor;

a terminal terminated to the CNT conductor, the terminal having a crimp barrel that receives the CNT conductor; and

a conductive intermediary electrically coupled to the CNT conductor and the terminal to enhance an electrical connection between the CNT conductor and the terminal, the conductive intermediary comprising a post extending from the terminal, the CNT conductor being wrapped around the post and doubled back into the crimp barrel.

2. The electrical connector of claim **1**, wherein the conductive intermediary comprises a soft metal that conforms to and spreads into the CNT conductor, the conductive intermediary being applied to at least one of the crimp barrel and the CNT conductor.

3. The electrical connector of claim **1**, wherein the conductive intermediary comprises a conductive paste on at least one of the crimp barrel and the CNT conductor.

4. The electrical connector of claim **1**, wherein the conductive intermediary comprises a soft metal that conforms to and spreads into the CNT conductor, the conductive intermediary being applied to at least one of the crimp barrel and the CNT conductor.

5. The electrical connector of claim **1**, wherein the conductive intermediary comprises a conductive paste on at least one of the crimp barrel and the CNT conductor.

6. The electrical connector of claim **1**, wherein the conductive intermediary comprises a conductive layer on at least one of the crimp barrel and the CNT conductor.

7. The electrical connector of claim **6**, the conductive layer being malleable and being formed into the CNT conductor when heat and/or pressure is applied to the conductive layer.

8. An electrical connector comprising:

a carbon nanotube (CNT) conductor;

a terminal terminated to the CNT conductor, the terminal having a crimp barrel that receives the CNT conductor; and

a conductive intermediary electrically coupled to the CNT conductor and the terminal to enhance an electrical connection between the CNT conductor and the terminal, the conductive intermediary comprising openings in the crimp barrel through a body defining the terminal, the CNT conductor being laced into and out of the crimp barrel through the openings.

9. The electrical connector of claim **8**, wherein the conductive intermediary comprises a conductive layer on at least one of the crimp barrel and the CNT conductor.

10. The electrical connector of claim **9**, the conductive layer being malleable and being formed into the CNT conductor when heat and/or pressure is applied to the conductive layer.

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